ACTA FACULTATIS XYLOLOGIAE ZVOLEN, 65(2): 5−11, 2023
Zvolen, Technická univerzita vo Zvolene
DOI: 10.17423/afx.2023.65.2.01

DENSITY OF BEECH (*Fagus sylvatica* L.) WOOD THROUGH A CROSS-SECTION OF THE TRUNK

Michal Dudiak

ABSTRACT

Differences in the density of beech wood in an absolutely dry state in individual zones: sapwood, mature wood, and false heartwood through a cross-section of the trunk are presented in the paper. The wood density of individual zones was determined with a digital density meter. Experimental measurements and subsequent statistical processing of the measured values showed that the density of beech samples with a false heartwood has a decreasing tendency through the cross-section of the trunk from the center of the trunk to the edge. The highest density $\rho_0 = 703.8 \pm 36.1$ kg.m^{-3} was observed in the dry state of beech samples with false heartwood. The density of mature wood in the absolutely dry state was 5.5% less compared to false heartwood, and the density of sapwood was 13.6 % less compared to false heartwood. The proven differences in the density of absolutely dry beech wood in the individual zones do not exceed the natural range of the density values of the beech wood (*Fagus sylvatica* L.) mentioned in the professional literature. For the above reason, it is not necessary to take into account the changes in the density of the wood through the cross-section of the trunk in common technical applications. The presented data contribute to the objectification of information about the properties of beech wood and enrich current knowledge.

Keywords: density wood; beech wood; sapwood; mature wood; false heartwood.

INTRODUCTION

European beech is a native tree of European forests. There are two species of beech on the European continent: *Fagus sylvatica* L. (from England and Sweden through West-Central-South-South-East Europe to the Balkans) and *Fagus Orientalis* (from the eastern part of the Balkan Peninsula through the Caucasus to Asia Minor) with very similar properties.

The wood of *Fagus sylvatica* L. belongs to the scattered-porous coreless woods with the possibility of forming a false heartwood. Sapwood and mature beech wood are medium-heavy, flexible, and easily split. It has good mechanical properties, it is plasticized, bent and machined very well. Its high permeability makes it well impregnated, stained and dyed. Beech wood is used to manufacture furniture, floors, sports equipment, toys and small household items. Sapwood and mature beech wood have a light white-gray color with a yellow tinge (Klement *et al.*, 2010, Dzurenda and Dudiak 2020.

A false heartwood beech is a growth defect that results from air-wood reactions in the mature wood zone. The color of the false heartwood beech is brown with a more or less

saturated shade. The primary cause of a false heartwood is injury to the trunk or branches of the tree, which allows air to enter the tree trunk. The oxygen contained in the air causes the oxidation of soluble carbohydrates and starch (contained in living or partially dead parenchymal cells), resulting in the formation of brown-colored polyphenolic compounds that penetrate into the neighboring tissues and color them (Bauch and Koch 2001, Račko and Čunderlík 2010).

According to the appearance of the false heartwood in the tree trunk and its shape on the cross-section of the trunk, the false heartwood is divided into: Round, Mosaic Stars, Flames (eccentric, centric) (Mahler and Höwecke 1991).

Compared to sapwood in a growing tree, mature wood and wood with false heartwood have a lower moisture content (Sachsse 1967, Torelli 1984, Kúdela and Čunderlík 2012) and according to the work of (Babiak *et al.*, 1990) lower permeability for liquids.

Wood density is one of the fundamental physical properties of wood, which is considered a basic indicator of wood quality (Wagenführ 2000, Bectaş *et al.*, 2002, Mišíková 2006). The density of wood is influenced by factors such as the conditions of tree growth, the elemental composition of wood, or the position in the tree trunk (Janota and Kurjatko 1978, Govorčin *et al.*, 2003, Gryc *et al.*, 2008).

The aim of the work was to determine the density of dry beech wood in the zone of sapwood, mature wood and false heartwood, to compare the differences between the densities of wood through the cross-section of the trunk and to analyze their causes.

MATERIAL AND METHODS

Material

34 trees with healthy false heartwood were selected for research from stands in the locations Štiavnické vrchy and Poľana, Slovakia. By transversal manipulation, a 1.2 m long cutout was made from the territorial part of each tree. By spreading out the central lumber with a thickness of h = 50 mm, blanks with a thickness of h = 32 mm were made (Fig. 1b).

Determination of density and color of samples

The density of sapwood beech was determined on wood samples made from blanks located on the edge of the center log. The density of beech mature wood was determined on wood samples made from blanks lying in front of the boundary line of the false heartwood in the central timber, and the density of beech wood of false heartwood was determined on wood samples made from blanks lying in the zone of false heartwood. Subsequently, the blanks were dried using the low-temperature drying mode of Dzurenda (2022) in a conventional hot air dryer to a moisture content of w = 12 ± 0.5%, with an emphasis on preserving the original color. The bedding surfaces of the dried blanks were machined on a FS 200 horizontal plane milling machine.

To verify the correctness of the classification of the blanks into the groups of wood from the zone of sapwood, mature wood and false heartwood, the color of dry wood on the planed surface was measured with a colorimeter Color reader CR-10 (Konica Minolta, Japan). The measured values were verified with the values of the color of beech sapwood, mature wood and false heartwood on the coordinates of the CIE L*a*b* color space obtained by Dzurenda *et al.* (2023) and given in Table 1.

Tab. 1 The color of the beech wood zones in the CIE L*a*b* color space (Dzurenda *et al.*, 2023).

Zones of beech wood	Color space coordinates CIE L*a*b*			Chrome
	L*	a*	b*	C*
Sapwood	82.4 ± 1.9	8.1 ± 1.5	19.1 ± 1.6	20.7 ± 1.7
Mature wood	78.9 ± 2.4	7.6 ± 1.7	18.9 ± 1.9	20.4 ± 1.9
False heartwood	64.9 ± 4.9	12.9 ± 2.1	19.6 ± 1.7	23.5 ± 1.8

Samples for density determination were made from the wood of blanks from the sapwood zone, mature wood and false heartwood with dimensions: thickness h = 40 mm, width w = 40 mm and length l = 100 mm.

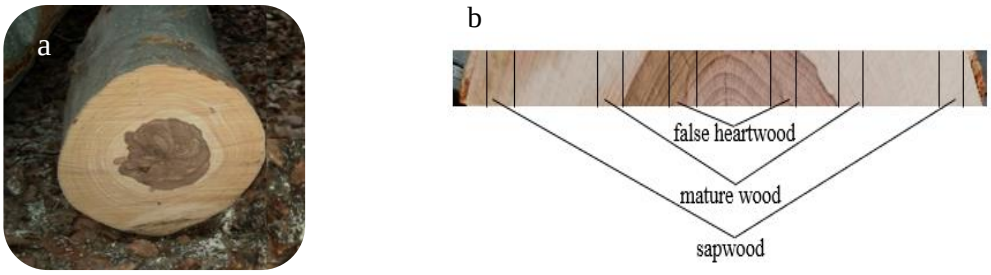

Fig. 1 a) view of the frontal section of the beech section, b) view of the milled beech wood with a proposal for sawing.

Determination of the density of dry beech wood

Before measuring the density, the manufactured test bodies of the individual groups were dried at a temperature of t = 103 ± 2 °C to a constant weight in a laboratory oven (MEMMERT UM110m, Niedersachsen, Germany). After drying, the samples were placed in a desiccator, and then, after cooling, the wood density was measured.

Determination of the density of beech samples of sapwood, mature wood and false heartwood in the dry state was carried out using a digital density meter: Set for determining the density of solid substances KIT 128 from the company Radwag (Poland) (Fig. 2) working on the principle of Archimedes' law.

Fig. 2 Measurement of the density of beech wood samples.

The density of sapwood, mature wood, and false heartwood samples was calculated using the equation:

$$\rho_0 = \frac{m_0}{V_0} = \frac{m_0}{\frac{m_0 - m_0^*}{\rho_{H_2O} \cdot g}} = \left(\frac{m_0}{m_0 - m_0^*}\right) \cdot \left(\rho_{H_2O} \cdot g\right) \quad [kg.m^{-3}] \qquad (1)$$

Where: m_0 – weight of dry sample [kg],

V_0 – dry sample volume [m^3],
m_0^* – weight of a dry sample immersed in distilled water [kg],
ρ_{H_2O} – density of distilled water at atmospheric pressure and temperature t = 14.5°C,
g – 9.81 $m.s^{-2}$ the gravitational acceleration of the Earth.

The density meter has built-in software that automatically determines the wood density from the data measured and confirmed by the operator, it is compatible with the computer software Excel 2019, which transfers and records in a table all the entered and measured density data of the given wood sample (Dudiak (2021).

Statistical processing of measured data

From the measured density data across the width of the trunk in individual zones, i.e., zone of sapwood, mature wood and false heartwood of beech, graphic dependences of the density distribution of beech wood through the width of the trunk were determined using the program Statistica 12 (V12.0 SP2, USA). With the help of statistical methods of evaluation using t-test and analysis of variance (ANOVA), it was evaluated whether there is a relationship between individual groups of samples and the determination of the size of the level of significance through the *p*-value. Program processing of the measured results partially eliminated the influence of measurement errors caused by the heterogeneity of wood and the method of measuring wood density.

RESULTS AND DISCUSSION

The density values of beech wood in individual zones (sapwood, mature wood and false heartwood) evaluated using statistical methods are shown in Table 2.

Tab. 2 Statistical evaluation of measured density data of absolutely dry beech wood.

Zones of beech wood	Number of measurements n	Average value ρ_0 [$kg.m^{-3}$]	Standard deviation s_x [$kg.m^{-3}$]	ρ_0 +95.00 %	ρ_0 -95.00 %	Significance level (*p*-)
Sapwood (SW)	30	608.2	23.8	632.0	584.4	0.000[a]
Mature wood (MW)	30	665.2	30.5	695.7	634.7	0.000[a]
False heartwood (FHW)	30	703.8	36.1	739.9	667.7	0.000[a]
SW & MW	60	608.2 & 665.2	23.8 & 30.5	632.0 & 695.7	584.4 & 634.7	0.000 [a]
SW & FHW	60	608.2 & 703.8	23.8 & 36.1	632.0 & 739.9	584.4 & 667.7	0.004 [a]
MW & FHW	60	665.2 & 703.8	30.5 & 36.1	695.7 & 739.9	634.7 & 667.7	0.362

Note: [a] statistically significant effect ($p < 0.05$).

The results of the statistical processing of the measured values of the densities of dry beech wood showed the differences in the density of the wood in the absolutely dry state through the cross-section of the trunk. The density of wood decreased from the center to the edge through the cross-section of the trunk. The difference between the density in the absolutely dry state of false heartwood and mature wood was about $\Delta\rho_0$ = 38.6 $kg.m^{-3}$ ($\Delta\rho_0$ = 5.5%) and between false heartwood and sapwood was about $\Delta\rho_0$ = 95.6 $kg.m^{-3}$ ($\Delta\rho_0$ = 13.6 %).

The average values of the density of beech wood in individual zones are shown graphically in Fig. 3.

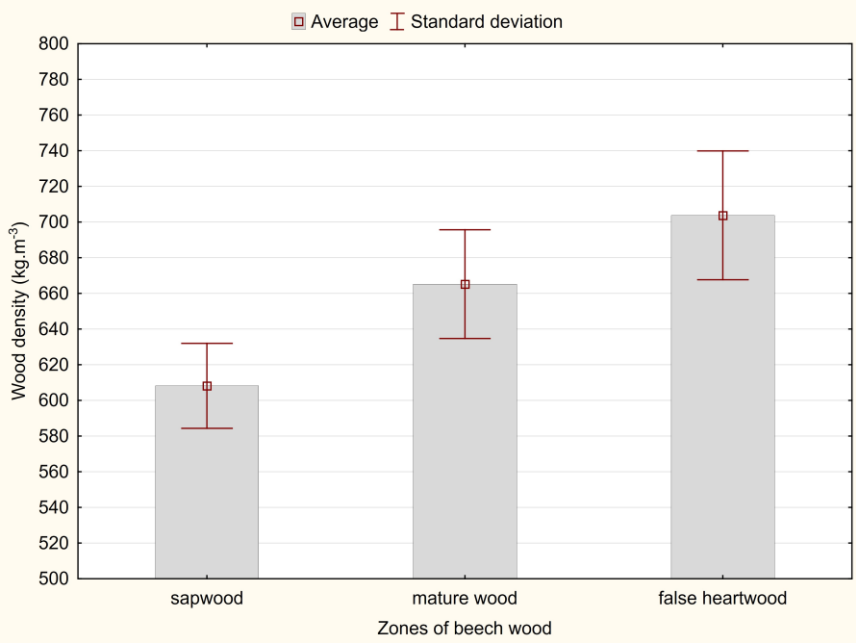

Fig. 3 Measured values of the density of individual zones of beech wood.

The reasons for the different density of beech wood in individual zones are:

a) The density of sapwood beech in an absolutely dry state is formed by cell walls of libriforous fibers, blood vessels, parenchymatic cells and air in the lumens of these structural elements of wood matter (Čunderlík 2009);
b) The higher density of mature beech wood than the density of sapwood is caused by the following factors:
   - lignification of cell walls, as stated by the authors Nečesaný (1958), Požgaj *et al.* (1997), and Čunderlík (2009);
   - filling of vessel lumens with tyle (Brown *et al.*, 1952, Chovanec and Korytárová 1989, Babiak *et al.*, 1990, Čunderlík 2009);
c) An increase in the density of beech wood with a false heartwood compared to mature wood is also caused by the presence of nuclear substances formed by biochemical processes during the formation of the false heartwood (Jacenko-Chmelevskij 1954, Nečesaný 1958, Bauch and Koch 2001, Čunderlík 2009, Račko and Čunderlík 2010).

The difference between the wood densities of false heartwood and mature wood was not significant, which is documented by the approximate agreement of the minimum value of the density of false heartwood and the average values of the density of mature wood, or maximum values of mature wood density and average values density of false heartwood.

The values of the densities of beech samples in individual zones through the cross-section of the trunk are within the interval of the range of natural variability of the density of beech wood 490-880 kg.m^{-3} reported in (Regináč *et al.*, 1990, Požgaj *et al.*, 1997, Molnár *et al.*, 2001, Makovíny 2010, Gryc *et al.*, 2008, Kuriatko *et al.*, 2010, Klement *et al.*, 2010, Dzurenda and Dudiak 2020). From the above, it follows that the presented values of the densities of the analyzed samples of beech wood do not need to be taken into account in technical applications in the construction industry, in the production of furniture, or in construction and carpentry products.

The presented values of the densities of dry beech sapwood, mature wood and false heartwood supplement the current hints about the properties of beech wood and contribute to the objectification of information about beech wood.

CONCLUSION

The article presents the values of the density of beech wood in an absolutely dry state in individual zones: sapwood, mature wood, and false heartwood through a cross-section of the trunk. The average values of the density of beech wood decrease through the cross-section from the center of the trunk to its circumference. Sapwood beech has the lowest average value in the dry state ρ_0 = 608.2 kg.m^{-3}. The average value of dry mature beech wood is ρ_0 = 665.2 kg.m^{-3}, which is $\Delta\rho_0$ = 57.0 kg.m^{-3} higher than that of sapwood, and the density of wood with a false heartwood ρ_0 = 703.8 kg.m^{-3} is $\Delta\rho_0$ = 95.6 kg.m^{-3} higher than sapwood.

The reasons for the increase in the density of mature beech wood and false heartwood are the lignification of the cell walls, the siltation of the lumens, and, in the case of false heartwood, the formation of nuclear substances in the false heartwood during the growth of the tree.

The proven differences in the density of absolutely dry beech wood in individual zones do not exceed the natural range of beech wood density values reported in the professional literature, and therefore it is not necessary to take into account the change in wood density through the cross-section of the trunk separately in common technical applications. The presented data contribute to the objectification of knowledge about the properties of beech wood, and the current ones enrich and expand them.

REFERENCES

Čunderlík, I., 2009. Wood structure. Technical university of Zvolen, Slovakia 135 p. ISBN 978-80-228-2061-5

Babiak, M., Čunderlík, I., Kúdela, J., 1990. Permeability and structure of beech wood. IAWA bulletin, 11(2): 115.

Bectaş I., Güller C., Baştürk M.A., 2002. Principal mechanical properties of eastern beech wood (Fagus orientalis Lipsky) naturally grown in Andirin Northeastern Mediterranean Region of Turkey. Turkish Journal of Agriculture and Forestry, 26: 147–154.

Bauch, J., Koch, G., 2001. Biologische und chemische Untersuchungen über Holzverfarbungen der Rotbuche (Fagus sylvatica L.) und Möglichkeiten vorbeugender Maßnahmen. Abschlussbericht, Bundesforschungsanstalt für Forst- und Holzwirtschaft, Universi-tät Hamburg, 2001.

Diaconu D., Wassenberg M., Spiecker H., 2016. Variability of European beech wood density as influenced by interactions between treering growth and aspect. Forest Ecosystems 3-6.

Dudiak, M., 2021. Modification of maple wood colour during the process of thermal treatment with saturated water steam. Acta Fac. Xylologiae Zvolen 2021, 63, 25–34.

Dzurenda, L., Dudiak, M., 2020. Changes in wood tree species *Fagus sylvatica* L. and characteristics of the thermal process of modify-ing its color with saturated water steam. Advances in ecological and environmental research. 2020, 5, 142-156.

Dzurenda, L., 2022. Mode for hot air drying of steamed beech blanks while keeping the colours acquired in the steaming process. Acta Facultatis Xylologiae Zvolen. Zvolen, 64(1), 81-88.

Dzurenda, L., Dudiak, M., Kučerová, V., 2023. Differences in Some Physical and Chemical Properties of Beechwood with False Heartwood, Mature Wood and Sapwood. Forests, 14, 1123. https://doi.org/10.3390/f14061123

Govorčin S., Sinković T., Trajković J., Despot, R., 2003. Bukovina. Zagreb, Common beech in Croatia: 652–669.
Gryc, V., Vavrčík, H., Gomola, Š., 2008. Selected properties of European beech (*Fagus sylvatica* L.). Journal of forest science, 54, (9): 418–425.
Chovanec, D., Korytárová, O., 1989. Signs of the first phase of beech steaming. Drevo, 44, 311.
Jacenko-Chmelevskij, A.A., 1954. Fundamentals and Methods of Anatomical Study of Wood. Moskva-Leningrad.
Janota, I., Kurjatko, S., 1978. Variability of beech wood density. Wood research. 23, pp. 25–40.
Klement, I., Réh, R., Detvaj, J., 2010. Basic characteristics of forest trees - processing of wood raw material in the wood processing industry. Zvolen: NLC. 82 p.
Mahler, G., Höwecke, B., 1991. Verkernungserscheinungen bei der Buche in Baden- Württemberg in Abhängigkeit von Alter, Standort und Durchmesser. Schweiz. Z. Forstwes. 142: 375−390.
Makovíny I., 2010. Useful properties and use of different types of wood. TU Zvolen, Zvolen.
Mišíková O., 2006. The hardness and density of beech wood from necrotic wounds and opposite wood. Proceedings of the 5th International Symposium Wood Structure of Properties 06. Zvolen, Arbora Publishers: 309–311.
Molnár, S., Németh, R., Fehér, S., Tolvaj, L., Papp, G., Varga, F., 2001. Technical and technological properties of Hungarian beech wood consider the red heart. Wood research, 46(1), 21-30.
Nečesaný, V., 1958. Beech false heartwood, structure, origin and development. Publishing House of the Slovak Academy of Sciences, Bratislava. 256 p
Požgaj, A., Chovanec, D., Kurjatko, S., Babiak, M., 1997. Structure and properties of wood. Bratislava, Slovakia, Príroda, 1997, 485 p.
Račko, V., Čunderlík, I., 2010. Mature wood as a limiting factor in the formation of a false heartwood beech (*Fagus sylvatica* L.). Acta facultatis xylologiae Zvolen,52 (1), 15 – 24.
Reginác, L., Babiak, M., Beničák, J., Dubovský, J., Kurjatko, S., Ladomerský, J., Makovíny, I., Požgaj A., 1990. The science of wood II. ES-VŠLD. 424 p.
Sachsse, H., 1967. Uber das wasser/gas - verhaltnis im holzporenraum lebender bäume im hinblick auf die kernbildung. Holz als Roh und Werkstoff, 25: 291−303.
STN 49 0108. Wood. Determination of density, 1993.
STN EN 13183–1. Moisture Content of a Piece of Sawn Timber–Part1: Determination by Oven Dry Method; Slovenian Institute for Standardization: Ljubljana, Slovenia, 2003.
Trenčiansky, M., Lieskovský, M., Merganič, J., Šulek, R., 2017. Analysis and evaluation of the impact of stand age on the occurrence and metamorphosis of red heartwood. Forest - Biogeosciences and Forestry, 10(3):605-610.
Torelli, N., 1984. The ecology of discolored wood as illustrated by beech (*Fagus sylvatica* L.). IAWA Bulletin 5(2): 121−127.
Vilkovská, T., Klement, I., Výbohová, E., 2018. The effect of tension wood on the selected physical properties and chemical composi-tion of beech wood (*Fagus sylvatica* L.) Acta facultatis xylologiae Zvolen, 60 (1):31 – 40.
Wagenführ R., 2000. Holzatlas. Leipzig, Fachbuchverlag Lepzig: 707.

ACKNOWLEDGMENT

This experimental research was prepared within the grant project: VEGA 1/0256/23 Research on the sapwood and the false heartwood of Beech wood for the purpose of eliminating the differences in the color of the wood by steaming with saturated water steam and also the support of the APVV grant agency within the framework of the APVV 21-0051 project.

AUTHOR ADDRESS

Michal Dudiak
Technical University in Zvolen
T. G. Masaryka 24
960 01 Zvolen, Slovakia
xdudiak@tuzvo.sk